An Approach of Enhancement of Cardiac Magnetic Resonance Images and Performance Evaluation

SHORT SYNOPSIS

Submitted in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

to

Manav Rachna International Institute of Research and Studies
(Deemed to be University)

by

Radhika R.
Registration number: 19/Ph.D/109

Under the supervision of

Dr. Rashima Mahajan
Professor, FET, MRIIRS

FACULTY OF ENGINEERING AND TECHNOLOGY

MANAV RACHNA INTERNATIONAL INSTITUTE OF RESEARCH & STUDIES

SECTOR-43, SURAJKUND –DELHI ROAD, FARIDABAD – 121001

FACULTY OF ENGINEERING AND TECHNOLOGY

Certificate

I hereby declare that the short synopsis "An Approach of Enhancement of Cardiac Magnetic Resonance Images and Performance Evaluation" being submitted in partial fulfillment of the requirement for the degree of Doctor of Philosophy in Computer Science and Engineering under Faculty of Engineering and Technology of Manav Rachna International Institute of Research & Studies, Faridabad during the academic year 2021-22.

It is a bona fide record of original work carried out under the supervision of Dr. Rashima Mahajan and has not been submitted in full or part to any other university or institute for degree or diploma. Further, it is certified that short synopsis is plagiarism free and proof has been submitted.

(Radhika R.)
19/Ph.D/109

Signature of the Supervisor
Dr. Rashima Mahajan
Professor, CSE Dept, FET, MRIIRS

(Chairperson, DRC)

(Chairperson, CDP)

ABSTRACT

Medical imaging plays a crucial role in the process of clinical disease diagnosis. The medical images X-ray, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) need to undergo the process of enhancement which greatly helps the medical specialists to precisely identify the nature of illness in the patients. Most of the people worldwide are affected by the cardiac diseases which may lead to the mortality. Early identification of the cardiac diseases may lead towards the improvement in the survival rate of the cardiac patients. Echocardiography and Cardiac Magnetic Resonance imaging (CMR) are the imaging modalities used in the early detection of the cardiac disorders. Cardiac Magnetic Resonance provides the better visualization of heart segments than Echocardiography. Enhancing the MRI Cardiac images is a necessity that may lead to the apt diagnosis of cardiac disorders by the doctors. Conventional image contrast enhancement techniques fail to reduce the unwanted noise due to presence of dust or scratches on the image capturing device that subsequently occurs in medical images. Further, the Histogram Equalization based methods lead to the over enhancement of the medical images. The primary aim of the proposed research is to identify the MRI cardiac image dataset and to apply the efficient pre-processing techniques to remove the unwanted noise. This will be followed by the improvement of contrast of the noise-free cardiac images to preserve the edge information and naturalness of the images. The enhanced set of images shall be evaluated by analyzing the values of parameters including Peak Signal to Noise Ratio (PSNR), Entropy, Image Enhancement factor (IEF), Absolute Mean Brightness Error (AMBE) and the image contrast. The outcome of the research will give rise to the clear visualization of the cardiac MRI images which would aid physician to diagnose the cardiac disorders at early stages for improved recovery.

Keywords: Cardiac Magnetic Resonance Imaging, Echocardiography, Peak Signal to Noise Ratio, Entropy, Image Enhancement factor, Absolute Mean Brightness Error, Contrast.

CONTENTS

S. No.	Description	Page No.
1	Introduction	1-4
	1.1 Image Enhancement	2
	1.2 Classification of Image Enhancement Techniques	3
	1.3 Applications of Medical Image Enhancement	4
	1.4 Challenges in Medical Image Enhancement	4
2	Literature Review	5-16
	2.1 Gaps in Study	16
3	Description of Broad Area	17-23
	3.1 Motivation	23
	3.1 Problem Statement Formulation	23
4	Objectives of the Study	24
5	Proposed Methodology	25-26
6	Expected Outcomes of the Research	27
	References	
	Plagiarism Report	

1. Introduction

Medical image enhancement makes use of various sources of images X-rays, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) for processing. Among these X-ray is the oldest medical image source, where the ionized radiations penetrate the tissues, this imaging technology helps the medical specialists for viewing some tissues and skeletal systems. X-rays has the limitations that it does not provide the detailed diagnostic related information of organs or tissues, but only the images. Medical field uses x-rays nowadays, although there is advancement in medical imaging technologies such as CT scan and MRI.

Computed Tomography scans provides the detailed images of the internal organs including tissues and aid the doctors to identify any irregularity in the patient's organs or tissues such as tumors, or any complications. These scans are prominently used in the detection of cancer, injuries in bones, imaging of lungs and chest which combines the use of x-rays for imaging and provide the visualization of the soft tissue details. On the other hand, Magnetic Resonance images are suitable for evaluation of soft tissues, such as to identify the spinal cord injury, brain tumors, ligament and tendon injury. These scanners generate the images of the organs using strong magnetic field and radio waves. Magnetic Resonance imaging modality provide the anatomy of the images in 3 planes: sagittal-plane from side, coronal-plane from front, and transverse-plane from top/down. Soft tissue details acquired through MRI are much more elaborative than a CT scan as it provides subtle differences between the soft tissues. The major advantage of MRI based imaging is that the image contrast can be set by making small variations in the radio waves and magnetic fields as these variations in the contrast settings spot the different tissues.

Cardiac failure or Congestive Heart Failure is a major problem affecting millions of people worldwide that occurs due to certain conditions such as hypertension, chronic renal failure, metabolic syndromes. Imaging modalities such as Echocardiography, Magnetic Resonance Imaging helps to detect clinical changes earlier. Screening and subsequent decision making for preventive treatment of cardiac disorders are achieved with these medical imaging techniques. Echocardiography utilizes the principle of interacting the ultrasound waves with the cardiac tissues resulting in the phenomena of reflection, scattering, refraction and

attenuation. Echocardiography and Cardiac magnetic resonance imaging are used to get the enhanced tissue characterization, cardiac motion analysis and also cardiac performance analysis due to stress.

These medical imaging technologies provide information to assess and check variations for congestive heart failure with comorbidities (Zibaei, M. 2017). Early identification of cardiac fibrosis and hypertrophy is achieved using echocardiography and cardiac MRI. Cardiac magnetic resonance imaging possesses the benefit over the other imaging modalities for the examination of patients with hypertrophic cardiomyopathy (HCM). The transthoracic echocardiography technique fails to image some heart segments, whereas cardiac magnetic resonance has technical advantages over echocardiography. It provides better visualization of cardiac segments compared to echocardiography which identify the presence of Left ventricular hypertrophy, identification of myocardial fibrosis, assessment of myocardial ischemia, dynamic Left Ventricular Outflow Tract (LVOT) obstruction, diastolic dysfunction and Mitral Regurgitation (MR) (Brenes, Doltra and Prat, 2018). Cardiac magnetic resonance imaging provides accurate wall thickness across the entire ventricle than Echocardiography which is of good image quality and endocardial /epicardial definition. Although early identification of cardiac defects is achieved using Echocardiography, however for more accurate, detailed visualization and subsequent analysis of human heart for healthy and disease specific biomarkers, cardiac magnetic resonance imaging is gaining popularity. By considering the importance of these medical images, image enhancement process is applied to these images for the early and effective medical diagnosis of cardiac patients.

1.1 Medical Image Enhancement

Medical images generally suffer from low contrast, irrelevant information/noise which is a hindrance to the doctors for clear examining of medical images. The quality of medical images plays a vital role in medical practice as it may affect the subsequent diagnosis at physician end. The enhancement of these medical images may lead towards guiding the specialist in more accurate detection of health issues. Any image enhancement process applied to these medical images need to fulfill the following major goals:

- Medical image contrast needs to be raised while maintaining the naturalness of the image.

- The unwanted noise from the medical images that occurs during image acquisition need to be removed.
- Medical images are required to be enhanced in a way so that the edge details of the medical images remain preserved.
- Maintaining the brightness of the medical images for obtaining pathological features for subsequent disease diagnosis.

1.2 Classification of The Image Enhancement Techniques

Medical image enhancement is implemented both in the spatial domain which operates on the image pixel and in the frequency domain which focusses on the Fourier transform of the image. The classification of the image enhancement techniques is as shown in Figure 1.

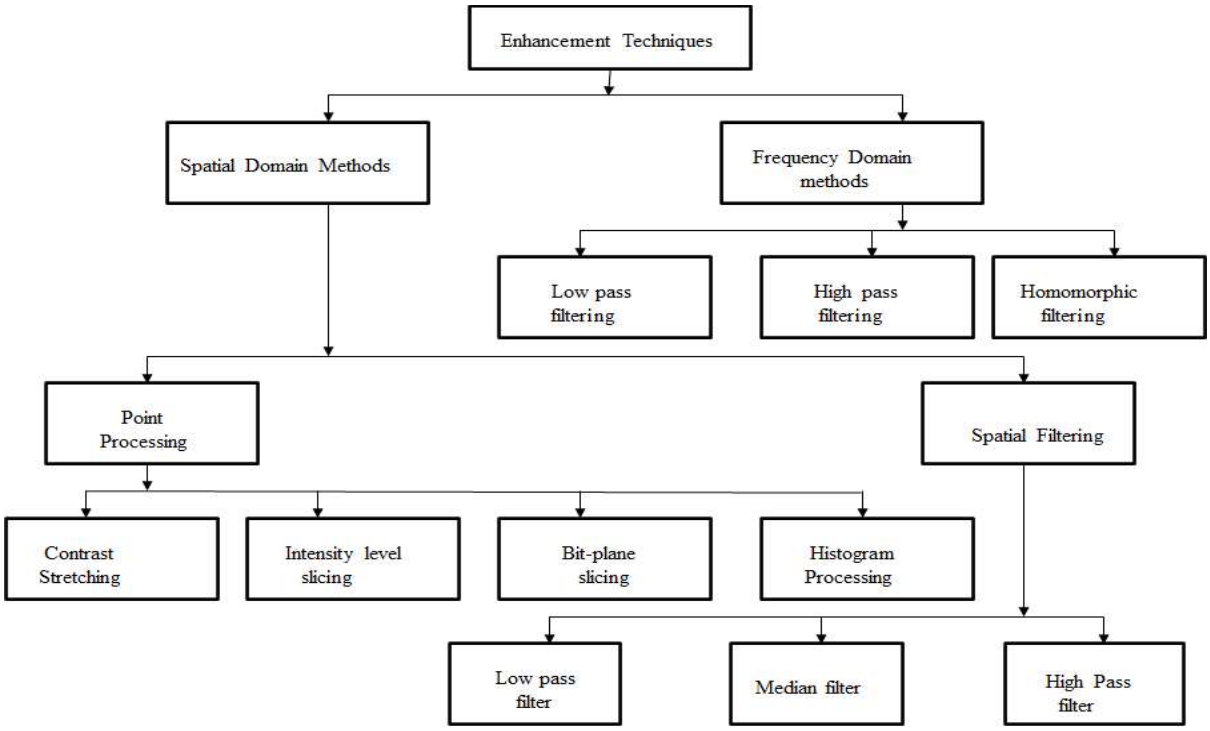

Figure 1. Classification of the Image Enhancement Techniques (Source-Self)

Image processing on spatial domain focusses majorly on point processing methods. The alteration of the intensity values using particular transformation technique is termed as point processing. In neighborhood processing the operations are performed on the image pixel and its immediate neighbors. The process of linear spatial filtering uses the concept of the convolution. This can be achieved by using a spatial mask and filtering is acheived by the sum

obtained by multiplying the pixels in an image with spatial mask component. Histogram Equalization deals with the global and local enhancement of the medical images. Frequency domain operations are based on the frequency content of the image. Smoothing and Sharpening of the images are achieved using the filtering approaches in the frequency domain approach.

1.3 Applications of Medical Image Enhancement

Medical image enhancement finds applications in multiple domains including:

- Identification of Brain tumours.
- Lesion detection in spinal cord.
- Medical treatment planning and observing/monitoring the response to the treatment.
- Breast cancer detection.
- Differentiation of normal and infarcted myocardial tissue.
- Detection of Myocardial scars, fibrosis.
- Examination of gastrointestinal tumours.
- Detection of the broken bones.
- Identification of benign and malignant lesions in the organs such as kidneys, liver.

1.4 Challenges in Medical Image Enhancement

- Thresholding based and wavelet based medical image denoising to prevent data corruption and retaining the important features of the medical images.
- Medical image preprocessing based on smoothing and sharpening of the image details while removing the noise.
- Enhancemnt based on intensity transformation, histogram processing, transforms for contrast improvement for clear anatomy visualization and pathology signs.

The enhanced images support the medical specialist for planning early and accurate treatment what they cannot achieve just by the physical examination of the patients. The detailed description of medical image enhancement techniques is provided in the section 3 that deals with description of the broad area. The detailed literature of the selected research area is provided in the next section.

2. Literature Review

Literature discusses about the different image enhancement techniques and their implementation details. Researchers discussed about the various enhancement techniques implemented in the spatial domain and in the frequency domain. Histogram based techniques comes under the spatial domain point processing approach of medical image enhancement. Further, image sharpening, noise reduction can be achieved using the spatial filtering techniques. In frequency domain based image enhancement techniques, the enhancement process is obtained by applying transforms such as Discrete Fourier transform, Discrete cosine transforms, Fast Fourier transform, Hartley transform, Haar transform, Slant transform etc.

Wadud, M. A. Al *et al.* (2007) proposed dynamic Histogram Equalization (HE) method which is used for the betterment of the image contrast. This approach partitioned the histogram into sub-histograms, which distributes the total dynamic gray level range to the sub-histograms using input gray level range and cumulative distributive function of the histogram. The traditional histogram equalization method is applied on each subhistogram for mapping the input gray levels into output gray levels. This approach is not suitable in some cases where we need to preserve the brightness of the images.

Huang, S. C., Cheng, F. C. and Chiu, Y. S. (2013) applied the gamma corrections method in histogram modifications by adjusting the gamma parameter that stretches the intensity of the image. The traditional gamma correction method produces the brighter image than the original image if the value of gamma is less than 1, otherwise produces the darker image if the value of gamma is greater than 1. Different values of gamma parameter will generate different contrast enhanced image. This technique analyzed the histogram based on probability, followed by the use of weighting distribution for smoothing and finally with the use of gamma correction the contrast of the image is improved and distortion in images, video sequences were reduced, but this method fails to deal with images possessing local and global bright regions.

Magudeeswaran, V., Ravichandran, C. G. and Thirumurugan, P. (2017) developed fuzzy based brightness preserving bi-histogram equalization in which fuzzy histogram is computed by multi-peak identification, threshold computation, image fuzzification, intensification and the fuzzy histogram is splitted into sub-histograms based on mean value

and then histogram equalization was applied. The work was based on the brightness preserving bi-histogram equalization (BPBHE) that not only preserved the brightness of the image, naturalness of the image but also prevented the increased enhancement in contrast but failed to remove impulse noise. The approach analyzed that the values of structure similarity index matrix, feature similarity index matrix that shows the similarity among the original and enhanced brain images were close to one with the increased values of average information content.

Joseph *et al.* (2017) analyzed the feature degradation of the magnetic resonance images based on the clip limit variations that determines the threshold based on which histogram of the image is clipped, and size of the non overlapping blocks on which magnetic resonance image was divided. Contrast-Limited-Adaptive-Histogram-Equalization (CLAHE) partition the imported image into non-overlapping tiles/blocks and these tiles are enhanced individually. The variation of indices which quantifies the feature degradation based on the clip-limit for Rayleigh, exponential and uniform distributions were observed. The optimum clip limit was set to 0.01 and the optimum-histogram specification was exponential.

Agarwal, M. and Mahajan, R. (2018) presented a combination of techniques in which segmentation of the input image histogram was done using Otsu's threshold, the threshold between the lower-gray-level of the object and the higher-gray-level of the background, weighted probabilities used for each sub-histogram, histogram equalization applied on sub-histogram followed by gamma-correction and homomorphic-filtering. Adaptive gamma correction was done by modifying the gamma parameter with cumulative distribution function that increases the intensity values. Homomorphic filtering which operates in frequency-domain removes the non-illumination artifacts of the low contrast image. This approach provided the better contrast improvement with maximum entropy and brightness preservation.

Bhairannawar, S. S. (2018) designed a technique for the enhancement of images using Adaptive Histogram Equalization (AHE). The technique was applied on both the color images and gray images, where the color images requires transformation from Red Green Blue (RGB) to Hue Saturation Value (HSV), then it was subjected to adaptive histogram equalization in which the enhancement takes place in a smaller region called tile and contrast enhancement on each pixels depends on the intensity values of the immediate neighboring pixel, followed by the calculation of local variance, local correlation and luminance enhancement along with the

contrast stretching which involves enhancing the saturation component. The gray image was put through the Laplacian operator which is good for identifying fine details of the image, then adaptive histogram equalization was applied to produce the enhanced image.

Maheshan, M. S., Harish, B. S. and Nagadarshan, N. (2018) developed an enhancement technique to improve the sclera segmentation results which combines histogram equalization and contrast level adaptive histogram equalization. This approach used histogram equalization with Fuzzy C- Means, K-Means and contrast limited adaptive histogram equalization with Fuzzy C-Means and K-Means. The efficiency of the enhancement techniques was evaluated based on the results of the segmentation. The approach produced increased precision rate for histogram equalization with Fuzzy C-Means, K-Means than contrast level adaptive histogram equalization with Fuzzy C-Means, K-Means.

Cao, G. *et al.* (2018) developed an enhancement method by integrating adaptive pixel value stretching and the gamma corrections. The dynamic pixel gray level gets extended to a full spectrum and global intensity are corrected adaptively in the enhanced image, adaptive method was considered to automatically determine the gamma parameter. The approach has the advantage of low computational complexity with less image distortion.

Chang, Y. *et al.* (2018) designed an approach where clip points were determined based on dynamic range of pixel in contrast limited adaptive histogram equalization. This approach first uses the gamma correction parameter to increase the luminance of the image, and the second gamma corrections were applied to deal with dark images and to prevent from over enhancement of the brighter regions of the input image.

Pawar, M. M. and Talbar, S. N. (2018) analyzed the mammographic images which are used in the early detection of the breast cancer. The three-level decomposition of the original mammographic image and the contrast limited adaptive histogram mammographic image are done using the Discrete Wavelet Transform (DWT) and using the fusion rule the approximate coefficients are averaged and based on maximum entropy the detail coefficients are combined, the final enhanced mammogram image is reconstructed using Inverse Discrete Wavelet Transform (IDWT). This approach prevented the enhancement of other part along with lesion region which mislead segmentation along with prevention from noise amplification.

Agrawal, S. *et al.* (2019) proposed a method in which the input image, the average of the input image were taken in which each intensity value of image pixels is replaced with an

average intensity value of its neighboring pixel. A joint histogram was computed from the original and the average image which is used to obtain the two-dimensional cumulative distributive function. The mapping procedure produced the output image with a wider range of gray-level scale. This method provided the better results in terms of contrast, details, brightness preservation and even enhancement of the input images.

Kuo, C. F. J. and Wu, H. C. (2019) proposed the Guassian probability model along with bi-histogram equalization. The work used the Guassian probability function as the probability density function and the cumulative density function was obtained, which is the input for histogram expansions. The Guassian model was divided into two parts based on the threshold and cumulative density function of the Guassian model was modified. The approach enhanced the target information to obtain the enhanced pathological features of the medical images and the background information is inhibited.

Yao, L. and Muhammad, S. (2019) applied a technique of histogram equalization along with super pixel segmentation that is simple linear iterative clusterring. Here, the original and the enhanced images were analyzed after applying the super pixel segmentation for both the images and it was compared with other algorithms such as quickshift, watersheds, Felzenswalb segmentation algorithms. The simple linear iterative clustering algorithm clearly distinguished between the original image and the histogram equalized image. It was observed that only simple linear iterative clustering super pixels are uniform and compact for the histogram equalized image compared to simple linear iterative clustering super pixels before histogram equalization.

Subramani, B. and Veluchamy, M. (2020a) enhanced the contrast resolution properties in the medical images. In this approach input image exposure value was found along with threshold computation which represent the amount of intensity exposure of an image. Based on the exposure threshold, histogram of the input image was divided into lower and upper image histogram that are clipped, equalized independently and by image fusion forms the improved image. The technique enhanced the structural information of the medical images with the preservation of fine details, reduced noise.

Subramani, B. and Veluchamy, M. (2020) proposed a method to enhance the color images in which the color channels were stretched and the color transformation was performed, the cumulative distribution function were used to determine the gamma parameter for gamma

correction, along with partitioning of the input image histogram into four sub-histograms based on mean value. The clipping and equalization were performed on each partition separately and the enhanced color images were obtained by inverse color transformation. The method produced highest entropy value and it was close to the input image and saturation metric of 0.535 was obtained.

Li, Z. *et al.* (2020) proposed an enhancement method in which the wavelet transform was applied on the original image and the histogram equalized image, the average of the low frequency coefficients of the decomposed sub images were taken and the fourth high frequency component was sharpened twice and subjected to median filtering for noise removal, finally the enhanced image was formed by the fusion of four sub images. The algorithm enhanced the visual quality of the medical images with lowest processing time, minimal distortion and improved efficiency.

Sahnoun, M. *et al.* (2020) enhanced the spinal cord MRI images with adaptive gamma correction along with Discrete Wavelet Transform (DWT) and singular value decomposition. The method decomposed the spinal cord MRI image into four frequency sub bands and the gamma correction was applied on the singular value decomposed low-low frequency band. The method well differentiated the spinal cord multiple sclerosis lesions and the artefacts excluding other pathologies similar to multiple sclerosis lesions along with good edge, structure, feature, details and brightness preservation.

Yugander, P. *et al.* (2020) presented a technique to remove the high-level salt and pepper noise in the Brain MR images using adaptive weighted mean filtering, which uses variable window sizes based on maximum and minimum pixel values in windows. Denoised medical images were subjected to homomorphic filtering which is an illumination reflectance model. The method was analyzed with the parameters peak signal-to-noise ratio, signal to noise ratio, mean square error and performed well compared with median filter and based on pixel density filter.

Ashiba, H. I. (2020) developed an enhancement method based on three approaches where the first approach decomposed the angiographic images into six subbands using additive wavelet transform and homomorphic processing was applied on each bands to strengthen the details. The second approach performed histogram equalization on sub blocks of angiographic images and based on modifications on clip limit images were enhanced. The third approach

performed modification on histogram equalization to obtain enhanced image, further additive wavelet transform was performed on the enhanced image along with homomorphic processing on subbands. The enhancement method was evaluated with the parameters Sobel edge magnitude, average gradient, entropy and the third approach produced better visual quality of the angiographic images.

Anilet Bala, A., Aruna Priya, P. and Maik, V. (2021) proposed an adaptive histogram equalization tuned with non similar grouping curvelet to enhance the fundus image degraded by the noise, color distortion, nonuniform illumination. The approach decomposed the noisy fundus image into individual color channels, the spatial filtering was performed on each channels along with the application of curvelet and its inverse transform on the filtered output. The contrast enhancement was done on each channels using the contrast limited adaptive histogram equalizations and the three channels are merged to produce enhanced color fundus image. The parameters such as peak signal-to-noise ratio, structural similarity index, correlation coefficient were improved by 17.66%, 0.93% and 0.24%, respectively.

Mishro, P. K. *et al.* (2021) enhanced the contrast of the brain magnetic resonance image using stationary wavelet transform and joint histogram equalization. The low contrast brain magnetic resonance image were decomposed into high and low frequency bands, where the low frequency image was splitted into sub images using the mean-value, then the joint histogram and the equalized pixel values of the sub-images were computed. The equalized pixel intensity values of created sub images were mapped into a single low-contrast enhanced image. The image was reconstructed using inverse stationary wavelet transform which combined the high frequency coefficient with enhanced low frequency coefficient. The method retains the anatomical details of the input brain images with the identification of the lesion.

Jana, B. R. *et al.* (2021) developed pixel-density based trimmed median filter technique to remove salt and pepper noise from the grayscale, color images. The method examined whether the test pixel is corrupted with salt and pepper noise or not based on the value of 0 or 255. Based on the test pixel as center pixel 3×3 window was taken and checked for the similar pixels in the window, where the median values of the pixels of the selected window was used to replace the test pixel. The denoised approach was evaluated with the parameters peak signal-to-noise ratio, structural similarity index, image enhancement factor and correlation index. Researchers have proposed and developed various algorithms based on the point processing

approach which includes the intensity level transformations such as gamma corrections, contrast stretching, histogram processing and filtering.

Mehmood, S. *et al.* (2022) developed the method in which the lung and colon hispathology images acquired and converted to the size of the model's specification. The resized images were provided with the model for training and validation in which the preliminary results evaluated in terms of accuracy, precision, F1-score, recall, specificity and misclassification rate. The class selective image processing identifies the underperforming class and the histogram equaliztion technique was applied to improve the image quality of the identified class. The approach reduced the time and computational cost along with the early detection of lung and colon cancer.

The literature reveals that apart from the spatial domain approaches such as histogram equalization, intensity transformation, contrast stretching, spatial filtering, the frequency domain approach using transforms, homomorphic filtering are also applied for enhancing the medical images such as X-rays, Brain MRI, Spinal Cord MRI, lung CT image, MR Bone, Mammograms to achieve the noise reduction, brightness preservation, edge detail preservation and contrast enhancement. The literature summary of the enhancement techniques is shown in Table 1.

Table 1. Literature Summary of the techniques used in Image Enhancement

Author, Year	**Methodology**	**Dataset**	**Parameters**	**Remarks**
Huang, S. C., Cheng, F. C. and Chiu, Y. S. (2013)	Transformation technique with gamma correction.	Black Board image, Truck image, Warplane image, Viaduct image	Entropy, Average Difference (AD)	Enhancement of both image and video sequence to raise the contrast.
Magudeeswaran, V., Ravichandran, C. G. and Thirumurugan, P. (2017)	Brightness preserving bi-histogram equalization (BPBHE)	MRI brain images	Entropy, Structure Similarity Index Measurement (SSIM) Feature Similarity Index Measurement (FSIM), Average Information Content, Natural Image Quality Evaluator	Significant change in Brain MRI brightness is prevented.

Joseph *et al.* (2017)	Contrast Limited Adaptive Histogram Equalization (CLAHE)	MR images	Absolute Mean Brightness Error (AMBE), Peak Signal to Noise Ratio (PSNR), Entropy	Preservation from the textural, intensity and geometrical features degradation of MR images.
Agarwal, M. and Mahajan, R. (2018)	Histogram Equalization with weighted distribution, gamma parameter, homomorphic filtering	X-ray, MRI images	Entropy	Entropy preservation improved, Prevention from the over enhancement. Better contrast improvement.
Bhairannawar, S. S. (2018)	Adaptive histogram equalization (AHE)	MedPix Database	Mean Square Error (MSE), PSNR	Better color contrast, Brightness improved, Sharpened edges of medical images.
Maheshan, M. S., Harish, B. S. and Nagadarshan, N. (2018)	Contrast Limited Adaptive Histogram Equalization	Sclera segmentation and Recognition Benchmarking competition	Accuracy, precision	Improved Sclera segmentation results due to enhancement.
Cao, G. *et al.* (2018)	Pixel value stretching with gamma parameter	Kodak, CSIQ and BSD500	Patch Based Contrast Quality Index (PCQI)	Restored lost illuminance of the image.
Chang, Y. *et al.* (2018)	CLAHE, Dual Gamma Correction	Carnival, Church, Basket Ball, Campus, Memorial Church	AMBE, Total Variation (TV)	Contrast and luminance in local regions are enhanced.
Pawar, M. M. and Talbar, S. N. (2018)	Discrete Wavelet transform (DWT) decomposition, DWT coefficient fusion and reconstruction	Mammographic Image Analysis Society (MIAS) The Tata Memorial Cancer Hospital (TMCH)	Edge Content, Edge Based Contrast Measure, Feature Similarity Index Measure, AMBE	Mammographic images with improved visual information, Helpful in accurate segmentation.
Agrawal, S. *et al.* (2019)	Joint histogram equalization	www/http://sipi.usc.edu/database/S, 2018; www/http://r0k.us/graphics/kodak/S, 2018	AMBE, Edge Based Contrast Measure, Discrete Entropy	Better brightness, color and contrast preservation.
Kuo, C. F. J. and Wu, H. C. (2019)	Bi-Histogram Equalization (BHE) with Guassian probability function.	Brain MRI, Lung CT Mackay Memorial Hospital.	Entropy, Contrast, Skewness difference, AMBE	Betterment in the medical images. pathological features contrast.

Yao, L. and Muhammad, S. (2019)	Histogram Equalization and superpixel segmentation	BrainWeb Harvard medical school website Open Access Biomedical Image Search Engine	Number of super pixels, compactness	Differentiation between the histogram equalized image and original image.
Subramani, B. and Veluchamy, M. (2020a)	Exposure Based Contrast limited bi-histogram equalization	MR Bone image, MR Cardiac Infarct, MR Brain image, MR Neck image, MR Breast image	PSNR, Discrete Entropy, Contrast Improvement Index, Michelson Contrast Ratio, Weber Contrast Ratio	Improved contrast, Maintain brightness and visual display. Better visibility of multiple sclerosis lesions.
Subramani, B. and Veluchamy, M. (2020)	Quadrant dynamic clipped Histogram Equalization, gamma correction	TID 2008, 2013 and IRCCyN/IVC	Entropy, contrast, colourfulness, saturation	Entropy, Colourfulness, Saturation preservation.
Li, Z. *et al.* (2020)	Wavelet transform, Histogram Equalization	CT images	PSNR, Structural Similarity Index Measure (SSIM), Root Mean Square Error, Entropy	CT images with reduced noise, Improved contrast, Less processing time.
Sahnoun, M. *et al.* (2020)	Adaptive gamma correction, Discrete Wavelet Transform, Singular Value Decomposition	Spinal Cord MRI	Entropy, Enhancement measure of Entropy, PSNR, AMBE, SSIM, FSIM, Edge Based Structural Similarity (EBSIM), Edge Preservation Index (EPI)	Brightness preservation, Edge details preservation. Better multiple sclerosis lesions visibility.
Yugander, P. *et al.* (2020)	Adaptive Weighted Mean Filtering, homomorphic filtering	MR Brain images (OASIS Dataset)	MSE, PSNR	High level Salt and Pepper noise removed.
Ashiba, H. I. (2020)	Additive Wavelet Transform (AWT) with homomorphic method	Angiographic Images	Entropy, Average gradient, Contrast Improvement factor, Sobel edge magnitude point	Better enhanced blood vessel image, vein image.
Anilet Bala, A., Aruna Priya, P. and Maik, V. (2021)	Contrast limited adaptive histogram equalization, Curvelet Transform	Color fundus image	PSNR, Structure Similarity Index, Correlation coefficient	Enhanced fundus image with better removal of noise.
Mishro, P. K. *et al.* (2021)	Stationary wavelet transform, Joint histogram equalization	Brain magnetic resonance image	MSE, Edge-Based-Contrast-Measure (EBCM), Quality-Aware-Relative-Contrast-Measure (QRCM)	Identification of lesion with structural details retainment.

Jana, B. R. *et al.* (2021)	Pixel-density based trimmed median filter	Gray scale, Color test images	PSNR, SSIM, Image Enhancement Factor, Correlation Index,	Removal of low to high density impulse noise.
Mehmood, S. *et al.* (2022)	Class selective image processing. Histogram equaliztion	Hispathology images	Accuracy, Precision, F1-score, Recall, Specificity and Misclassification rate	Early detection of lung and colon cancer. Reduction of time and computational cost.

According to WHO statistics an estimate of 17.9 million people died of cardiac disease in 2016, which represent 31% of the global death. The rising proportion of cardiac failure may lead to mortality and morbidity. The increase in survival rate after cardiac failure can be achieved with the imaging modalities Echocardiography and Cardiac Magnetic Resonance (CMR) imaging. This section presents the importance of Cardiac Magnetic Resonance over the Echocardiography in the early identification of the cardiac problems.

Cardim, N. *et al.* (2015) specified the use of multimodality cardiac imaging approach for hypertrophic cardiomyopathy patients. The authors presented the importance of Cardiac Magnetic Resonance which produces the report of left ventricle volume, mass and ejection fraction, degree of asymmetry, type, distribution of hypertrophy, Left Ventricular Outflow Tract (LVOT), Late Gadolinium Enhancement (LGE), mitral valve apparatus in patients with hypertrophic cardiomyopathy along with Late Gadolinium enhancement used for assessing the tissue characterization and correct anatomy information were specified.

Oda, S. *et al.* (2017) studied the use of myocardial strain analysis on cardiac magnetic resonance to identify cardiac amyloidosis. The authors used cardiac magnetic resonance with Late gadolinium enhanced (LGE) imaging and cardiac magnetic resonance tagging for patients. The study found that 48 patients were LGE-positive and 13 patients were LGE-negative out of 61 patients with systemic amyloidosis, the peak circumferential strain was found to be low in LGE-positive patients than in LGE-negative also the variability in peak circumferential strain time was significantly greater in LGE-positive than in LGE-negative.

Maron, M. S., Rowin, E. J. and Maron, B. J. (2017) presented the importance of cardiac magnetic resonance in the initial evaluation of patients with hypertrophic cardiomyopathy which provides the reliable measurement of left ventricle wall thickness that leads to further diagnosis. The study also specified that cardiac magnetic resonance was used in differentiating

morphological structures crista supraventricularis and left ventricle papillary muscles from the left ventricle wall, as these initial evaluation lead to assessment/screening of family members for hypertrophic cardiomyopathy.

Storz, C. *et al.* (2018) studied three subjects with diabetes, prediabetes and normal controls to characterize the changes in myocardium with the help of cardiac magnetic resonance. These findings included end-diastolic volume, left ventricular ejection fraction, myocardial mass, left ventricle remodeling index, late gadolinium enhancement, T1 native, extracellular volume fraction, fibrosis volume and cell volume and it was observed that left ventricle remodelling index was significantly higher in participants with prediabetes and diabetes, independent of body mass index (BMI), hypertension, age and sex, while extracellular volume fraction was lower in participants with prediabetes and diabetes compared with healthy controls, cell volume was significantly higher in subjects with prediabetes and diabetes as compared with controls.

Galderisi, M. *et al.* (2019) specified the diagnosis of hypertrophic cardiomyophathy in athelete's heart with the help of cardiac MRI. The study reported the enlarged Left Ventricle (LV) with LV-end diastolic diameter and septal thickness measurement along with the existence of myocardial fibrosis of anterior and inferior septum with Late Gadolinium enhancement. The authors also specified that cardiac magnetic resonance imaging provides the volume measurement and ejection fraction better than echocardiography with late gadolinium enhancement.

Manole, S. *et al.* (2021) observed the cardiac volumes computed using both echocardiography and cardiac MRI with mixed healthy subjects and patients with atrial fibrillation. The study included participants grouped into 63 subjects with atrial fibrillation and 63 healthy subjects for computation of left atrial volume and 51 subjects with atrial fibrillation and 30 helath subjects for computation of left-ventricular end-diastolic cardiac volume, end-systolic cardiac volume and left-ventricular ejection fraction. Excellent correlation was observed for determination of cardiac volumes between echocardiography and cardiac magnetic resonance.

Goolaub, D. S. *et al.* (2022) demonstrated a method for volumetric fetal flow imaging with magnetic resonance imaging. Three orthogonal multisliced stacks acquired using radial multidimensional phase contrast magnetic resonance imaging and reconstructed into flow

sensitive time series images with motion correction and image based cardiac gating. The slices were combined into dynamic volume using slice-volume reconstruction and resolves interslice spatio temporal corregistration. The observations explained the complex mechanism of the fetal circulation that shunts oxygenated blood to the developing fetal brain and heart.

The above studies indicate that cardiac magnetic resonance reports are suitable for providing the anatomical information, ventricular wall thickness, volume and characterization of tissues. The enhancement technique shall be utilized to improve the cardiac magnetic resonance images that may lead to the early diagnosis of patients with hypertrophic cardiomyopathy, cardiac fibrosis, cardiac amyloidosis.

Medical image enhancement forms a crucial foundation for efficient diagnosis, screening and treatment of illness in patients. The image enhancement is the essential one as the medical images are complex in nature and do not carry sufficient information for correct diagnosis due to unwanted details, technical limitations, lightning conditions of imaging devices and these enhancement process forms the basis for further steps in image processing such as identification of region of interest of the images, classification and extraction of the features.

2.1 Gaps in Study

The highlights of gap in literature are listed below:

- Literature reports reveal that conventional contrast enhancement techniques still lack to reduce the unwanted noise due to presence of dust or scratches on the image capturing device that subsequently occurs in medical images (Subramani and Veluchamy, 2020a).
- The Histogram Equalization (HE) based methods may result in the over enhancement of the medical images (Li *et al.*, 2018).
- Medical enhancement techniques have mostly focused on two dimensional images and limited focus is found towards three dimensional images.
- Image enhancement in the field of cardiac MRI images is very less explored till date (Qin, Tarroni and Rueckert, 2021).

Hence, there is a lot of scope to further explore an efficient cardiac MRI Image enhancement approach to aid early identification of cardiac diseases.

3. Description of Broad Area

Cardiac Magnetic resonance imaging is a useful technique in patient's evaluation with suspected or diagnosed cardiac disorders, which provides three- dimensional cardiac images without ionizing radiations and more beneficial in the quantification of ventricular volumes and functions. Basically, there are two types of sequences in cardiac magnetic resonance imaging. Spin-echo sequences provides information of anatomy, tissue characterization. Gradient echo sequences provide visualization of cardiac movements (cine), also quantify global and regional cardiac function.

Cardiac Image Datasets make its place in the research process which provides the diagnostic information, anatomical structures and provide access to the information. List of online datasets available are given in Table 2.

Table 2. List of online cardiac MRI datasets (Source-Self)

Datasets	Cardiac Modalities	Year	Remarks
Auckland MRI Research Group	Cardiac MRI	2006	Dataset of single patient with fully labeled MRI set of normal heart.
Sunnybrook Cardiac Data	Cine MRI	2009	Dataset of forty-five cine-MRI images of four Pathology group with the categories of heart failure with and without infarction, Hypertrophy.
Left Atrium Segmentation Challenge	Cardiac MRI	2013	Dataset comprises of thirty MRI images for atrial fibrillation management.
Atrial Segmentation Challenge	Late Gadolinium enhanced MRI	2018	Dataset of one hundred fifty-four 3D MRIs focused on atrial fibrillation pathology.

Enhancement of these cardiac magnetic resonance image is essential in order to remove the artifacts and the noise factors along with improvement of visual content of the image. Contrast enhancement algorithm are classified as spatial domain and frequency domain algorithm. Enhancement based on spatial domain approach comprises point processing and spatial

filtering. The point processing uses the following methods for the image enhancement (Gonzalez and Woods, 2007). The input and output intensity levels are denoted as r and s.

A. Image Negative

Consider an image with intensity level [0, L-1]. The intensity level of the image is reversed to get the negative. The negative of an image is defined as in equation (1).

$$s = L-1-r \quad (1)$$

This method is used to enhance the white or grey detail in the dark region of the image.

B. Logarithmic transformation

Logarithmic transformation maps the less narrow range input intensity values to more wider range output intensities. The transformation is expressed as in equation (2).

$$s = clog(1 + r) \text{ where c is a constant} \quad (2)$$

The aim is to expand value of dark pixels and compressing the higher values. Inverse Logarithmic transformation maps the wide range of intensity values into narrow range of intensity values.

C. Power-Law (Gamma Transformation)

The relation between the input intensity level r and output intensity level s is given by the power-law transformation specified in equation (3).

$$s = cr^{\gamma} \quad (3)$$

c and ϒ are positive constants.

The simplest form of transform-based gamma correction is derived as in equation (4). Huang, S. C., Cheng, F. C. and Chiu, Y. S. (2013).

$$T(I) = I_{max}(\frac{I}{I_{max}})^{\gamma} \quad (4)$$

Where I and I_{max} are the intensity of each pixel in the image and maximum intensity of pixel in the image, γ is a correction parameter, if $\gamma < 1$ the transformed image will be brighter than the input image, if $\gamma > 1$ the transformed image will be darker than the input image. Gamma correction methods are used to improve the brightness of the dimmed images and the probability distribution of the luminance pixel.

D. Contrast stretching

This method stretches the graylevel values in an image to the full dynamic range so that it improves the contrast. This stretching is a linear method of transformation of the images where the upper and the lower pixel value limit of the images are to be specified over which the image is subjected to stretching.

E. Gray level slicing

Intensity level slicing is used to highlight specific range of intensities so that it helps in enhancing flaws in medical images such as X-rays, CT. Gray level slicing works in two approaches in which gray level slicing without background displays high intensity values in particular region of image and low values to other regions by ignoring background, whereas gray level slicing with background displays high intensity values in particular region of images and original gray level to other region by preserving the background.

F. Bit –plane slicing

Pixel representation using one or more bits of the byte for the image is called bitplane slicing. Most significant bit (MSB) is used to represent the pixel,from the gray level to binary image. It aims at conversion of gray level into binary image, fewer bit image representation, making it as smaller size image and to enhance by focussing on the image.

G. Histogram Equalization (HE)

Enhancement techniques can be classifed as local and global in the spatial domain processing. Histogram forms the basis for spatial domain operations. Global enhancement focusses on the entire dynamic range, whereas concentrating on the smaller regions are defined as local. The following methods are used for global and local image enhancement.

Histogram Equalization technique is a global method used for contrast enhancement in the medical images and sretches the histogram across the entire range of grayscale. Histogram of an image with intensity range [0, L-1] is stated in equation (5).

$$h(r_k)=n_k \tag{5}$$

where r_k represents kth intensity value, n_k represents the count of image pixels having intensity r.

Normalized histogram is is computed using the equation (6).

$$p(r_k) = n_k/AB \quad (6)$$

Here k=0,1,2,….L-1, A and B are the row, column dimension that is total number of pixels in the image, $p(r_k)$ is the image intensity level (r_k) occurrence probability. The sum of all components of normalized histogram is 1. Bi-histogram equalization, Adaptive histogram equalization, Contrast limited adaptive histogram equalization focusses on the smaller regions for the local enhancement.

Histogram equalization uses the transformation function T(r), which is defined as cumulative distribution function of the probability density function of the intensity levels in a image. In case of continuous quantities of intensity levels normalized in the range [0, 1], where $P_r(r)$ is the probability density function of the intensity levels. The output intensity level s is obtained by the following transformation on the input intensity level r as stated in equation (7).

$$S = T(r) = \int_0^r \omega \, d(\omega) \quad (7)$$

where ω is a dummy variable of integration. The probability density function of the output level is uniform which is mentioned in equation (8).

$$P_s(s) = \begin{cases} 1 & 0 \ll s \ll 1 \\ 0 & otherwise \end{cases} \quad (8)$$

The intensity levels are equally likely and in the range [0 , 1]. This transformation of intensity level is called as cumulative distribution function. In case of discrete quantities of intensity levels the transformatioin function is given as in equation (9).

$$S_k = T(r_k) = \sum_{i=1}^{k} \frac{n_i}{n} \quad (9)$$

where k= 1,2 ….L, L represent the total number of intensity levels, S_k represent the output intensity value corresponding to input intensity value r_k, n_i is the ith intensity level, n is the total number of pixels. The histogram equalization method may lead to the overenhancement of the images which is not suitable for certain applications.

In neighborhood processing the smoothing linear spatial filter which is an averaging filter replaces the pixels using mean of intensity values in the neighborhood based on filter mask and is used to remove the details which are not relevant to the image. This filtering leads to the blurring of edges. Order-Statistics Non-Linear Filters also known as median filter replaces the image pixels with median of intensity values in the neighborhood. This method is effective in noise reduction and has less blurring compared with smoothing linear filters.

Median filters remove the salt and pepper noise as they appear as black and white dots on an image (Yugander *et al.*, 2020).

The frequency domain enhancement transforms the input image, performs enhancement and uses the inverse transform to retrieve the image in spatial domain as depicted in Figure 2. Based on the Fourier transform the operations are performed.

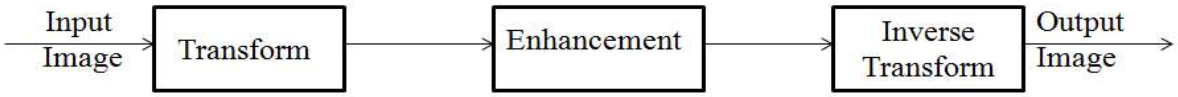

Figure 2. General form of processing in frequency domain (Source-Self)

Convolution theorem forms the basis of the frequency domain technique. For the spatial domain processing expressed in equation (10).

$$j(x, y) = k(x, y) * i(x.y) \tag{10}$$

i(x, y) is the input image, j(x, y) is the output image, k(x, y) is a function to enhance the image features.

The equivalent frequency domain relationship using the convolution theorem is defined in equation (11).

$$J(u, v) = K(u, v)\, I(u, v) \tag{11}$$

Where J, K and I are Fourier transforms, K is a transfer function which is used to enhance the certain features of an image.

Fourier transform (FT), Wavelet transform (WT), Curvelet transform, Contourlet transform are some of the transformations used in the image enhancement. Fourier transform represents the signal in sinusoids. It provides the signals localized in frequency domain. Wavelet transforms isolates edge discontinuities, it affects limited coefficient and handle point discontinuities, but doesn't handle curve discontinuities. Curvelet transform uses less coefficients and handles curve discontinuities. Contourlet transform captures contours and fine details of the image. Speckle noise is removed effectively by the algorithm based on contourlet transform (Do and Vetterli, 2005)

Smoothing is done in the frequency domain by low pass filtering which reduces the high frequency content of the Fourier transform. Edges and other changes in intensity are

connected with high frequency component so it needed to reduce the effect. Sharpening is achieved by high pass filtering which reduces the effect of low frequency component.
Homomorphic filtering is a technique used to improve the image grayscale appearance by intensity range compression (illumination) and contrast enhancement (reflection) simultaneously. Spatial domain technique works on the pixel and it changes the representation of the image, whereas frequency domain technique works on Fourier transform and it changes the image position.

The performance of medical image enhancement techniques is evaluated using various statistical metrics/parameters as explained below:

A. Mean Square Error (MSE)

Mean Square Error is computed as the average of square of errors of the input and the output images. The image with good quality has the minimum MSE value. It is specified as in equation (12).

$$MSE = \frac{1}{AB}\sum_{i=1}^{A}\sum_{j=1}^{B}\left(U_{i,j} - V_{i,j}\right)^2 \quad (12)$$

U and V are the input and output image matrices, A and B are the rows and columns of the image, i, j represent the index of A and B.

B. Peak Signal-to-Noise Ratio (PSNR)

Peak Signal-to-Noise Ratio is obtained as the ratio of maximum of power of signal to the noise power. This value should be large which denotes minimum power of noise. The relation of PSNR with MSE is given below in equation (13) (Patel *et al.*, 2020).

$$PSNR = 10\log\frac{255^2}{MSE} \quad (13)$$

C. Absolute Mean Brightness Error (AMBE)

Absolute Mean Brightness Error represents the average brightness preserving relationship between the input and output image after the enhancement and is expressed as equation (14).

$$AMBE = |E(u) - E(v)| \quad (14)$$

E(u) and E(v) are the means of input and output images. Smaller value of AMBE denotes the better brightness preserving effect (Kuo and Wu, 2019).

.

D. Image Enhancement Factor (IEF)

Image Enhancement Factor is used to find out the capability of edge preservation as defined in equation (15).

$$IEF = \frac{\sum_{i=1}^{A}\sum_{j=1}^{B}\left(N(i,j)-O(i,j)\right)^2}{\sum_{i=1}^{A}\sum_{j=1}^{B}\left(E(i,j)-O(i,j)\right)^2} \quad (15)$$

N(i, j) is the noisy image, E(i, j) is the enhanced image, O(i, j) is the original image (Gupta, Gandhi and Yadav, 2013).

3.1 Motivation

An estimate of 17.9 people died of cardiac diseases in 2016 according to WHO statistics which represent 31% of global death. The rising proportion of patients with cardiac failure may lead to increased mortality and morbidity. Cardiac MRI images provides the clear visualization and evaluation of human heart. Medical image enhancement is challenged with the processing of various imaging modalities. An efficient image enhancement solution of cardiac MRI images may result in the increase in the survival rate of the cardiac patients by the apt identification of the diseased/infected part from the enhanced images.

3.2 Problem Statement Formulation

The current progress through the literature has been accessed and is found that cardiac MRI image enhancement with higher accuracy is the need of the hour. The problem of the proposed research is identification of efficient and reliable medical image pre-processing techniques to remove dust/scratch specific noise from the input cardiac MRI images and eventually exploring the clinically relevant medical image enhancement methods by overcoming limitations such as over enhancement of input cardiac images faced by conventional image enhancement techniques.

4. Objectives of the Study

The objectives of the present research are :

- To explore different medical image enhancement techniques with respect to MRI cardiac images to understand the algorithmic details.
- To identify the MRI cardiac image (2D and 3D) specific online dataset to be used for the proposed research.
- To apply efficient pre-processing techniques to remove the unwanted noise (particularly dust and scratch specific noise) from the input cardiac MRI images.
- To enhance the contrast of the input MRI cardiac images while preventing them from over enhancement and retaining the original edge information.
- To reduce the loss of details in the cardiac MRI image and to preserve the brightness of the cardiac MRI images to maintain the associated diagnostic details.
- To evaluate the performance of image enhancement solution incorporated for the input cardiac MRI images by analyzing parameters including Peak Signal to Noise Ratio (PSNR), Image Enhancement Factor (IEF), Entropy, Absolute Mean Brightness Error (AMBE), enhanced image contrast and to qualitatively assess the technique based on the visual appearance of the images.

5. Proposed Methodology

The proposed methodology initially includes the import of cardiac MRI images into MATLAB workspace. Secondly, preprocessing of the cardiac images shall be done to remove the unwanted noise due to presence of dust or scratches on the image capturing device. An efficient enhancement technique shall be implemented to improve the contrast of the CMR images and also to prevent from over enhancement. The performance of the implemented approach shall be evaluated by analyzing important parameters including Peak Signal to Noise Ratio, Entropy, Average Mean Brightness Error, Image Enhancement Factor, Contrast. Finally, the results obtained using the implemented methodology shall be compared with the results of existing methodologies.

The flow of methodology to be adopted is depicted in Figure 3.

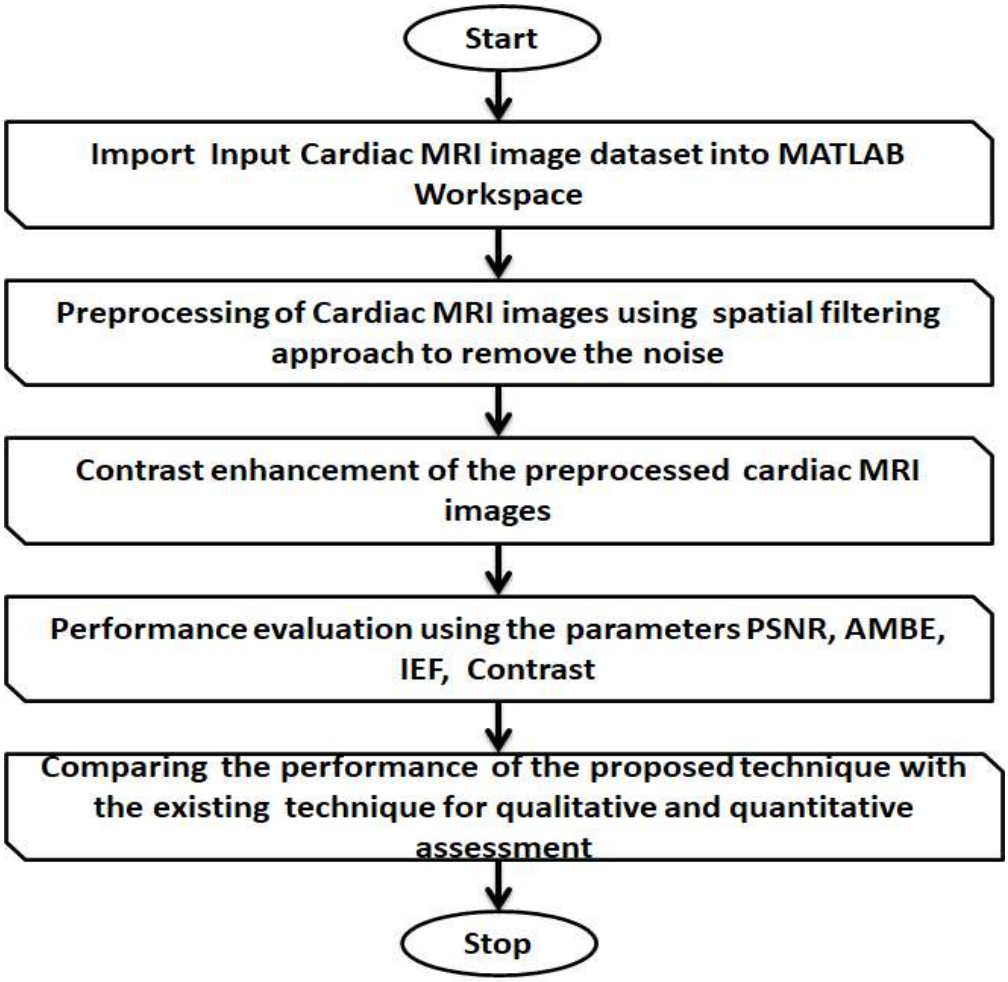
Start
Import Input Cardiac MRI image dataset into MATLAB Workspace
Preprocessing of Cardiac MRI images using spatial filtering approach to remove the noise
Contrast enhancement of the preprocessed cardiac MRI images
Performance evaluation using the parameters PSNR, AMBE, IEF, Contrast
Comparing the performance of the proposed technique with the existing technique for qualitative and quantitative assessment
Stop

Figure 3. Methodology to be followed for Cardiac MRI Enhancement (Source-Self)

Step 1: To import cardiac MRI images from the database into MATLAB workspace.

Step 2: Preprocessing of the Cardiac images shall be done by the filtering method which is used to remove the noise. MRI images are affected by different types of noises such as salt and pepper noise, Speckle noise, Poison noise, Guassian noise. The use of filter such as Weiner filter, Median filter, Guassian filter shall be explored to remove unwanted noise from cardiac MRI images.

Step 3: The enhancement of the Cardiac MRI images shall be attained with the selection of the appropriate spatial domain and the frequency domain techniques in order to raise the contrast, to preserve the original brightness and the edge information for the better visual appearance of the Cardiac MRI images.

Step 4: The performance of the enhancement algorithm shall be evaluated with the parameters like PSNR (Peak to Signal Noise Ratio), (AMBE) Average Mean Brightness Error, Entropy, IEF (Image Enhancement Factor), Contrast along with qualitative assessment.

The results obtained using the proposed methodology shall be compared with the results of the existing methodologies in the literature to record the improvement.

6. Expected Outcomes of the Research

1. Efficient MRI cardiac image enhancement of input images possessing high Peak Signal to Noise Ratio, Image Enhancement Factor, improved contrast and reduced Absolute Mean Brightness Error.
2. Robust model of cardiac MRI image enhancement with enhanced adaptability for images with distinct specifications for clear visual display of the cardiac images used in medical diagnosis.

References

Agarwal, M. and Mahajan, R. (2018) 'Medical Image Contrast Enhancement using Range Limited Weighted Histogram Equalization', *Procedia Computer Science*. Elsevier B.V., 125(2017), pp. 149–156. doi: 10.1016/j.procs.2017.12.021.

Agrawal, S. *et al.* (2019) 'A novel joint histogram equalization based image contrast enhancement', *Journal of King Saud University - Computer and Information Sciences*. King Saud University, (xxxx). doi: 10.1016/j.jksuci.2019.05.010.

Anilet Bala, A., Aruna Priya, P. and Maik, V. (2021) 'Retinal image enhancement using adaptive histogram equalization tuned with nonsimilar grouping curvelet', *International Journal of Imaging Systems and Technology*, 31(2), pp. 1050–1064. doi: 10.1002/ima.22504.

Ashiba, H. I. (2020) 'Feature enhancement angiographic images in medical diagnosis', *Multimedia Tools and Applications*. Multimedia Tools and Applications. doi: 10.1007/s11042-020-08899-2.

Bhairannawar, S. S. (2018) *Efficient medical image enhancement technique using transform HSV space and adaptive histogram equalization*, *Soft Computing Based Medical Image Analysis*. Elsevier Inc. doi: 10.1016/B978-0-12-813087-2.00003-8.

Brenes, J. C., Doltra, A. and Prat, S. (2018) 'Cardiac magnetic resonance imaging in the evaluation of patients with hypertrophic cardiomyopathy', *Global Cardiology Science and Practice*, 2018(3). doi: 10.21542/gcsp.2018.22.

Cao, G. *et al.* (2018) 'Fast contrast enhancement by adaptive pixel value stretching', *International Journal of Distributed Sensor Networks*, 14(8). doi: 10.1177/1550147718793803.

Cardim, N. *et al.* (2015) 'Role of multimodality cardiac imaging in the management of patients with hypertrophic cardiomyopathy: An expert consensus of the European Association of Cardiovascular Imaging Endorsed by the Saudi Heart Associationfile:///D:/Research

papers/cardiac paper', *European Heart Journal Cardiovascular Imaging*, 16(3), pp. 280-280hh. doi: 10.1093/ehjci/jeu291.

Chang, Y. *et al.* (2018) 'Automatic Contrast-Limited Adaptive Histogram Equalization with Dual Gamma Correction', *IEEE Access*. IEEE, 6, pp. 11782–11792. doi: 10.1109/ACCESS.2018.2797872.

da Cunha, A. L., Zhou, J. and Do, M. N. (2006) 'The nonsubsampled contourlet transform: Theory, design, and applications', *IEEE Transactions on Image Processing*, 15(10), pp. 3089–3101. doi: 10.1109/TIP.2006.877507.

Do, M. N. and Vetterli, M. (2005) 'The contourlet transform: An efficient directional multiresolution image representation', IEEE Transactions on Image Processing, 14(12), pp. 2091–2106. doi: 10.1109/TIP.2005.859376.

Galderisi, M. *et al.* (2019) 'The multi-modality cardiac imaging approach to the Athlete ' s heart : an expert consensus of the European Association of Cardiovascular Imaging The approach to the athlete ' s heart Definition of the athlete ' s heart and physiological le ventricular h', pp. 1–31.

Gonzalez, R. C. and Woods, R. E. (2007) *Digital Image Processing (3rd Edition)*, *Prentice-Hall, Inc. Upper Saddle River, NJ, USA ©2006*.

Goolaub, D. S. *et al.* (2022) 'Volumetric Fetal Flow Imaging with Magnetic Resonance Imaging', *IEEE Transactions on Medical Imaging*, 41(10), pp. 2941–2952. doi: 10.1109/TMI.2022.3176814.

Gupta, V., Gandhi, D. K. and Yadav, P. (2013) 'Removal of fixed value impulse noise using improved mean filter for image enhancement', *2013 Nirma University International Conference on Engineering, NUiCONE 2013*, pp. 28–30. doi: 10.1109/NUiCONE.2013.6780117.

Huang, S. C., Cheng, F. C. and Chiu, Y. S. (2013) 'Efficient contrast enhancement using adaptive gamma correction with weighting distribution', *IEEE Transactions on Image Processing*, 22(3),

pp. 1032–1041. doi: 10.1109/TIP.2012.2226047.

Jana, B. R. *et al.* (2021) 'Pixel density based trimmed median filter for removal of noise from surface image', *Applied Nanoscience (Switzerland)*, (0123456789). doi: 10.1007/s13204-021-01950-0.

Joseph, J. *et al.* (2017) 'An objective method to identify optimum clip-limit and histogram specification of contrast limited adaptive histogram equalization for MR images', *Biocybernetics and Biomedical Engineering*. Nałęcz Institute of Biocybernetics and Biomedical Engineering of the Polish Academy of Sciences, 37(3), pp. 489–497. doi: 10.1016/j.bbe.2016.11.006.

Kuo, C. F. J. and Wu, H. C. (2019) 'Gaussian probability bi-histogram equalization for enhancement of the pathological features in medical images', *International Journal of Imaging Systems and Technology*, 29(2), pp. 132–145. doi: 10.1002/ima.22307.

Li, Z. *et al.* (2020) 'An efficient and high quality medical CT image enhancement algorithm', *International Journal of Imaging Systems and Technology*, (June 2019), pp. 1–11. doi: 10.1002/ima.22417.

Magudeeswaran, V., Ravichandran, C. G. and Thirumurugan, P. (2017) 'Brightness preserving bi-level fuzzy histogram equalization for MRI brain image contrast enhancement', *International Journal of Imaging Systems and Technology*, 27(2), pp. 153–161. doi: 10.1002/ima.22219.

Maheshan, M. S., Harish, B. S. and Nagadarshan, N. (2018) 'On the use of image enhancement technique towards robust sclera segmentation', *Procedia Computer Science*. Elsevier B.V., 143, pp. 466–473. doi: 10.1016/j.procs.2018.10.419.

Manole, S. *et al.* (2021) 'Correlation between Volumes Determined by Echocardiography and Cardiac MRI in Controls and Atrial Fibrillation Patients', *Life*, 11(12), pp. 1–15. doi: 10.3390/life11121362.

Maron, M. S., Rowin, E. J. and Maron, B. J. (2017) 'How to image hypertrophic cardiomyopathy',

Circulation: Cardiovascular Imaging, 10(7), pp. 1–19. doi: 10.1161/CIRCIMAGING.116.005372.

Mehmood, S. *et al.* (2022) 'Malignancy Detection in Lung and Colon Histopathology Images Using Transfer Learning with Class Selective Image Processing', *IEEE Access*, 10, pp. 25657–25668. doi: 10.1109/ACCESS.2022.3150924.

Mishro, P. K. *et al.* (2021) 'A novel brightness preserving joint histogram equalization technique for contrast enhancement of brain MR images', *Biocybernetics and Biomedical Engineering*, 41(2), pp. 540–553. doi: 10.1016/j.bbe.2021.04.003.

Oda, S. *et al.* (2017) 'Identification and assessment of cardiac amyloidosis by myocardial strain analysis of cardiac magnetic resonance imaging', *Circulation Journal*, 81(7), pp. 1014–1021. doi: 10.1253/circj.CJ-16-1259.

Patel, S. *et al.* (2020) 'Comparative Study on Histogram Equalization Techniques for Medical Image Enhancement', *Advances in Intelligent Systems and Computing*, 1048(January), pp. 657–669. doi: 10.1007/978-981-15-0035-0_54.

Pawar, M. M. and Talbar, S. N. (2018) 'Local entropy maximization based image fusion for contrast enhancement of mammogram', *Journal of King Saud University - Computer and Information Sciences*. King Saud University. doi: 10.1016/j.jksuci.2018.02.008.

Qin, C., Tarroni, G. and Rueckert, D. (2021) 'in Cardiovascular Medicine (https://www.frontier Deep Learning for Cardiac Image Segmentation : A Review', pp. 1–53.

Sahnoun, M. *et al.* (2020) 'Spinal cord MRI contrast enhancement using adaptive gamma correction for patient with multiple sclerosis', *Signal, Image and Video Processing*. Springer London, 14(2), pp. 377–385. doi: 10.1007/s11760-019-01561-x.

Storz, C. *et al.* (2018) 'Myocardial tissue characterization by contrast-enhanced cardiac magnetic resonance imaging in subjects with prediabetes, diabetes, and normal controls with preserved

ejection fraction from the general population', *European Heart Journal Cardiovascular Imaging*, 19(6), pp. 701–708. doi: 10.1093/ehjci/jex190.

Subramani, B. and Veluchamy, M. (2020a) 'A fast and effective method for enhancement of contrast resolution properties in medical images', *Multimedia Tools and Applications*, 79(11–12), pp. 7837–7855. doi: 10.1007/s11042-019-08521-0.

Subramani, B. and Veluchamy, M. (2020b) 'Quadrant dynamic clipped histogram equalization with gamma correction for color image enhancement', *Color Research and Application*, 45(4), pp. 644–655. doi: 10.1002/col.22502.

Wadud, M. A. Al *et al.* (2007) 'A dynamic histogram equalization for image contrast enhancement', *IEEE Transactions on Consumer Electronics*, 53(2), pp. 593–600. doi: 10.1109/TCE.2007.381734.

Yao, L. and Muhammad, S. (2019) 'A novel technique for analysing histogram equalized medical images using superpixels', *Computer Assisted Surgery*. Taylor & Francis, 24(sup1), pp. 53–61. doi: 10.1080/24699322.2018.1560100.

Yousuf, M. A. and Rakib, M. R. H. (2010) 'An Effective Image Contrast Enhancement Method Using Global Histogram Equalization', *Journal of Scientific Research*, 3(1), p. 43. doi: 10.3329/jsr.v3i1.5299.

Yugander, P. *et al.* (2020) 'MR Image Enhancement using Adaptive Weighted Mean Filtering and Homomorphic Filtering', *Procedia Computer Science*. Elsevier B.V., 167(2019), pp. 677–685. doi: 10.1016/j.procs.2020.03.334.

Zhou, F. *et al.* (2017) 'Method of Improved Fuzzy Contrast Combined Adaptive Threshold in NSCT for Medical Image Enhancement', *BioMed Research International*, 2017. doi: 10.1155/2017/3969152.

Zibaei, M. (2017) 'Helminth Infections and Cardiovascular Diseases':, *Current Cardiology Reviews*, 13, pp. 56–62. doi: 10.2174/1573403X12666160803.

MANAV RACHNA
vidyaparikshan

Dr. O.P. Bhalla Central Library
Manav Rachna International Institute of Research and Studies
(A deemed-to-be-university under section 3 of UGC Act 1956)

SIMILARITY VERIFICATION CERTIFICATE

Title: ..... AN ..... APPROACH ..... OF ..... ENHANCEMENT ..... OF ..... CARDIAC ..... MAGNETIC ..... RESONANCE ..... IMAGES ..... AND ..... PERFORMANCE ..... EVALUATION

Researcher: ..... Radhika. R.

Registration Number: 19/PhD/109

Supervisor: ..... Dr. Rashima Mahajan

Department: ..... CSC .....

This is to certify that the above mentioned Short Synopsis/Thesis was scanned for similarity index through Turnitin Software on 30.3.22 ..... with submission ID 1797109522 and the similarity index was found to be ..... 10% ..... %. The complete report running into 30 ..... Pages, 7988 ..... Word count with File Size 4.34 ..... KB/MB is being forwarded to the Research Supervisor/DRC/DRB for review.

Date: 30.3.22

Rajesh Kumar
Dr. Rajesh Kumar
University Librarian
Dr. O.P. Bhalla Central Library
Manav Rachna International
Institute of Research & Studies
Faridabad

The complete report of the above Short Synopsis/Thesis has been reviewed and the similarity index is below the accepted norms as per the University Grants Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulations 2018. The Short Synopsis/Thesis may be considered for further processing

Research Scholar

Research Supervisor

An Approach of Enhancement of Cardiac Magnetic Resonance Images and Performance Evaluation

ORIGINALITY REPORT

10%	7%	11%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

Excluding matches less than 14 words

PRIMARY SOURCES

1	idr.nitk.ac.in Internet Source	1%
2	Pranaba K Mishro, Sanjay Agrawal, Rutuparna Panda, Ajith Abraham. "A novel brightness preserving joint histogram equalization technique for contrast enhancement of brain MR images", Biocybernetics and Biomedical Engineering, 2021 Publication	1%
3	edoc.mdc-berlin.de Internet Source	1%
4	Algorithm & SoC Design for Automotive Vision Systems, 2014. Publication	1%
5	Dawei Qi, Lei Yu. "Multifractal spectrum theory used to medical image from CT testing", 2008 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2008 Publication	<1%

6	archive.org Internet Source	<1 %
7	mafiadoc.com Internet Source	<1 %
8	A Anilet Bala, P Aruna Priya, Vivek Maik. "Retinal image enhancement using adaptive histogram equalization tuned with nonsimilar grouping curvelet", International Journal of Imaging Systems and Technology, 2020 Publication	<1 %
9	doctorpenguin.com Internet Source	<1 %
10	Monika Agarwal, Rashima Mahajan. "Medical Image Contrast Enhancement using Range Limited Weighted Histogram Equalization", Procedia Computer Science, 2018 Publication	<1 %
11	worldwidescience.org Internet Source	<1 %
12	Mozhgan Kalhor, Atefeh Kajouei, Fatemeh Hamidi, Morteza Modarresi Asem. "Assessment of Histogram-Based Medical Image Contrast Enhancement Techniques; An Implementation", 2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC), 2019 Publication	<1 %

13	www.ijert.org Internet Source	<1 %
14	link.springer.com Internet Source	<1 %
15	Oge Marques. "Practical Image and Video Processing Using MATLAB®", Wiley, 2011 Publication	<1 %
16	mgesjournals.com Internet Source	<1 %
17	e-neurospine.org Internet Source	<1 %
18	M S Maheshan, B S Harish, N Nagadarshan. "On the use of Image Enhancement Technique towards Robust Sclera Segmentation", Procedia Computer Science, 2018 Publication	<1 %
19	digital.library.txstate.edu Internet Source	<1 %
20	Gang Cao, Huawei Tian, Lifang Yu, Xianglin Huang. "Fast contrast enhancement by adaptive pixel value stretching", International Journal of Distributed Sensor Networks, 2018 Publication	<1 %
21	Vaithiyam Rengarajan Vijaykumar, Guru Santhanamari. "New decision-based trimmed	<1 %

median filter for high-density salt-and-pepper noise removal in images", Journal of Electronic Imaging, 2014
Publication

22	"ECR 2020 Book of Abstracts", Insights into Imaging, 2020 Publication	<1 %
23	cyberleninka.org Internet Source	<1 %
24	Bharath Subramani, Magudeeswaran Veluchamy. "Quadrant dynamic clipped histogram equalization with gamma correction for color image enhancement", Color Research & Application, 2020 Publication	<1 %
25	Seiji Takashio, Megumi Yamamuro, Tomoaki Uemura, Daisuke Utsunomiya et al. "Correlation Between Extent of Myocardial Fibrosis Assessed by Cardiac Magnetic Resonance and Cardiac Troponin T Release in Patients With Nonischemic Heart Failure", The American Journal of Cardiology, 2014 Publication	<1 %
26	Submitted to Aston University Student Paper	<1 %
27	K. Aono, M. Maruyama, T. Mori, H. Yamada. "Implementation of a bipolar real-time image	<1 %

signal processor-RISP-II", IEEE Journal of Solid-State Circuits, 1987
Publication

28	M. I. Ashiba, H. I. Ashiba, M. S. Tolba, A. S. El-Fishawy, F. E. Abd El-Samie. "An efficient proposed framework for infrared night vision imaging system", Multimedia Tools and Applications, 2020 Publication	<1 %
29	Meenakshi M. Pawar, Sanjay N. Talbar. "Local entropy maximization based image fusion for contrast enhancement of mammogram", Journal of King Saud University - Computer and Information Sciences, 2018 Publication	<1 %
30	Mouna Sahnoun, Fathi Kallel, Mariem Dammak, Omar Kammoun, Chokri Mhiri, Kheireddine Ben Mahfoudh, Ahmed Ben Hamida. "Spinal cord MRI contrast enhancement using adaptive gamma correction for patient with multiple sclerosis", Signal, Image and Video Processing, 2019 Publication	<1 %
31	Submitted to Punjab Technical University Student Paper	<1 %
32	Submitted to Universiti Teknologi Malaysia Student Paper	<1 %

Exclude quotes	On	Exclude matches	< 14 words
Exclude bibliography	On		